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Design and Technical Testing for Crude Biodiesel Reactor Using Dry Methods: Comparison of Energy Analysis

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Abstract

The objectives of this study were to design biodiesel dry washing reactor and to analyze energy consumption between this method and water washing method. The reactor was disigned continously. The reactor exhibited washing capacity of 0.56 kg/minute, energy consumption of 315 kJ/kg, while energy consumption of water washing was1361kJ/kg. Biodiesel quality produced from the reactor meets the biodiesel standards: methyl ester was 98.65%, total glycerol was 0.24 %, acid value was 0.41mg NaOH/g oil, moisture content was 0.41 %, density was 0.86 kg/m^3, and viscosity was 6.00 cSt. The energy ratio between dry and water washing methods was 0.23.

Keywords: biodiesel, dry washing, energy consumption, energy ratio, biodiesel washing reactor

Nomenclature

cSt	centi Stoke
hp	horse power
kg/h	kilogram per hours
kg/min	kilogram per minutes
kj/kg	kilojoules per kilogram
kg/m^3	kilogram per cubic meter
MJ	Mega joules

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1. Introduction

The use of biodiesel as a diesel fuel substitute must be followed by the development of an efficient and economical technology [1]. This is in line with the road map of biodiesel in Indonesia which requires applying more advanced technology over time [2, 3]. Washing of crude biodiesel methods should be always continuously developed, due to the results of the process which will largely determine the quality of biodiesel, energy consumption, and overall production costs [4, 5, 6].

One of the weaknesses in the washing of biodiesel using water (water washing) is a long process that takes time. Purification by using water takes a long time (over 2.5 hours) and takes large amounts of water. The resulting waste can not be disposed into the environment and in addition it needs drying process to evaporate the residual water dissolved in the biodiesel [7, 8]. In the washing water for biodiesel, it uses hot water with temperature of 90-100^{o}C and conducted after the transesterification of fatty acids and the settling process. Water washing requires high energy because the heat supplied for heating water and drying for biodiesel which takes a relatively long time, and it is conducted repeatedly [9]. Several attempts have been made to reduce the use of water washing. Soerawidjaja [10] did the addition of acetic acid in the wash water and the results show that the use of acetic acid can reduce the use of water for washing crude biodiesel. Acetic acid is added to neutralize biodiesel and to remove residual sodium from biodiesel.

To lessen the use of water in the washing of crude biodiesel it needs a method that can eliminate water consumption. One of the methods that can be applied is dry method (dry washing) which is useful to remove all soap and dirt from crude biodiesel without using water. There are several ways to dry washing biodiesel. Setyaningsih *et al.* [8] and Braz [11] states biodiesel purification by washing or cleaning agent or absorbent technology is one of the solutions that can be offered. Dry washing methods can reduce water washing consumption up to 100%, shorten the purification process time of about 2.5 hours, reduce waste around 30%, and reduce operational costs or production.

One of the advantages of dry washing is much easier to operate. It does not produce waste water, reduce the risk of the presence of water in the fuel, and give the possibility for cleaning materials can be cleaned and reused. The disadvantages of biodiesel dry washing system are the additional equipment to perform dry washing column (membrane) and the pump, and when using resin it needs to be washed. Applied dry washing biodiesel is highly recommended because it will save water and time. In addition, to shorter time needed especially to get products ready, the sooner biodiesel produced the faster can be used [12].

Dry washing of biodiesel can provide high quality fuel that can meet international standards for biodiesel such as Standard Specification for Biodiesel Fuel(B100)-ASTM [13]. Capacity of the selected dry washing can be adjusted with the budget and the volume of biodiesel produced. Biodiesel dry washing system requires a minimum of energy and does not give waste wash water so it is more environmentally friendly. The aims of this study is to design biodiesel washing reactor using dry method, to conduct technical tests or performances of the reactor, and to compare energy analysis of biodiesel washing between dry and washing water method.

2. Material and methods

2.1. Materials

Materials used for testing biodiesel dry washing reactor comprises of crude biodiesel which resulted from transesterification process between palm oil and methanol, NaOH as a catalyst, and other chemicals for analysis. Biodiesel was processed from palm oil and methanol with molar ratio 1: 11.5. NaOH was used with the amount of 1% of the palm oil. The amount of biodiesel that is used both for dry and water washing was 10 kg.

2.2. Membrane column

Apparatus for this experiment was membrane column. Apparatus used for testing consisted of heater (1500 watts), volume measuring devices (measuring cups, baker glass, and erlenmeyer), viscometer, thermometer, analytical balance, and glassware for analysis. This research was conducted in the Laboratory of Process in Center for Agro-based Indusrey (CABI) Bogor and Workshop of CABI.

2.3. Methods

2.3.1. Structural and functional design

The main components of dry biodiesel washing reactor consists of: 1) membrane (ceramic material), 2) output valve, 3) pressure indicator I, 4) holder, 5) frame, 6) pressure indicator II, 7) input valve, 8) electric motor 1.5 hp, 9) pulley I, 10) gear pump, 11) pulley II, 12) feeder tank, 13) output valve , and 14) wheels. The type of membrane filter used was ultra-filtration membrane with the specifications i.e membrane area was 0.0055 m^2, length was 1200 mm, and porous size was 0.2-1.2 micrometers.

Feeder tank has capacity of 20 liters and was made of 1 mm stainless steel. Four cm square frame was used in such a way to prop up the washing reactor, while the electric motor (1.5 hp) was used to convey crude biodiesel inside the membrane and to drain purified biodiesel towards biodiesel tank. Pulley was used to reduce electric motor rpm to be one-third and it was conducted with applying diameter ratio of 1: 3. Gear pump was also installed with a purpose to reduce the rotation of the pulley. For ease the operation or mobility of reactor, then on the bottom of the reactor were installed 4 wheels and at the rear of the reactor, a holder was mounted to facilitate the equipment from one location to another.

2.3.2. Performance test

To determine the performance of biodiesel washing reactor, 10 kg of crude biodiesel was collected into the feeder tank. This tank serves to accommodate crude biodiesel to be washed or purified. Crude Biodiesel was flowed using rotary gear pumps into membrane such that crude biodiesel will be filtered out and flowed to the pipe covered the membrane, while the impurities that do not pass the filter will be trapped inside of the membrane. Refined biodiesel then will collect into outlet. Measurements of flow rate of dry washing of biodiesel was done by collecting 1 liter of refined biodiesel in one minute. The valve was used to control the flow pressure inside the membrane so that the flow rates will change depending on the valve position. Measurement of pressure biodiesel dry washing was done by observing at the scale of the pressure in the pressure indicator so it does not give effect to the heat of the electric motors used.

For washing biodiesel using water, 30 liters of water is heated at a temperature of 90 degrees Celsius. Hot water was then flowed into 10 kg of crude biodiesel repeatedly. Feeding of hot water is stopped when the water that passed through biodiesel has clear color and at the same time the water consumption for this washing method was calculated. Biodiesel were then dried at a temperature of 100-110 degrees Celsius until the air bubbles disappear.

2.3.3. Measurement of energy analysis

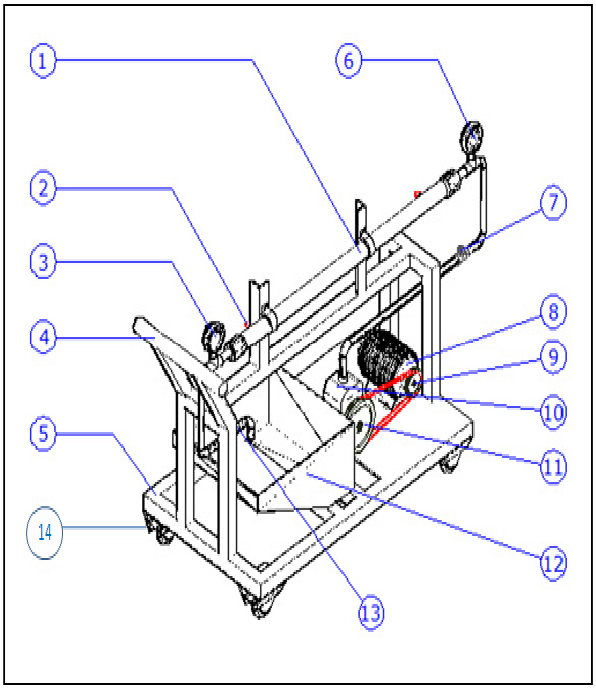
Measurement of the amount of energy required for dry washing was by measuring the power of 1.5 hp electric motor to filter crude biodiesel into membrane and to flow crude biodiesel from the tank to the feeder tank using a kWh-meter. It was also calculated the energy released from operators during the washing process takes place.

The energy consumption for water washing was also measured using kWh-meter. The measurement was done for : the measurement of heat energy released from heater (1500 Watts) for heating water up to 90^oC, the measurement of heat energy released from heater for drying biodiesel at a temperature of 110°C, and measurement of energy for drainage biodiesel and water for washing using electric pumps 250 watts. The energy released from operators was also measured. According to Stout [14], the energy released from operator can be calculated by multiplying the number of operators worked with a calorific value of human labor (0.94 MJ/person) divided by production capacity (kg/h).

3. Result and discussion

3.1. Test of biodiesel washing reactor

Technical drawings for biodiesel washing reactor using dry method can be seen in Figure 1. After the technical test of biodiesel washing reactor, the results of performance for several parameters such as washing capacity, processing time, pressure washing inside the membrane, the energy consumption of electric motors, and yield were obtained and exhibited in Table 1.



Caption :

1. Uf membrane ,
2. product
3. pressure indicator I
4. holder
5. frame
6. pressure indicator II
7. input valve
8. Electric motor
9. *pulley* I
10. gear pump
11. pulley gear- pump II
12. feeder tank
13. output valve
14. Wheels

Fig. 1. Technical drawing of biodiesel washing reactor (dry methods).

Based on the performance on Table 1, biodiesel dry washing method become more efective than water washing method. It was indicated with the washing capacity of dry washing method i.e 0.56 kg/minute meanwhile washing capacity for water washing (batch system) i.e 10 liter/2 hour or 0.07221kg/minute. Also, it can be calculated the ratio washing capacity of dry to water methods become 8.8 times. Dry methods was able to eliminate the use of 30 liters of water, and also it was no longer apply anymore water heating and drying stages or heater (1500 Watts). One point that should be paid attention in biodiesel washing using dry method, that is membrane allows accumulation of dirt or impurities that needed back wash for a certain period of time so that filtering can produce good quality of biodiesel.

At the beginning of biodiesel washing using water, the water has be milky white. Washing water was done several times until the wash water is actually clear. After washing followed by drying is done to eliminate the methanol content and lower water content of biodiesel is entrained in the washing process. Drying is done by heating the biodiesel at a temperature of 110 °C. Biodiesel drying result will be more shiny color. Biodiesel appearance resulted from dry method was less shiny, This due to the possibilities of dyes from palm oil still exist and it will disappear when exposed to heat.

Table 1. Performance test results of dry washing of biodiesel reactor.

Type of washing	Capacity (l/min)	Electric motor (hp)	Pressure (bar)	Heater (Watt)	Water consumption (l)
Dry washing (continues)	0.65	1.5	3-6	-	-
Water washing (batch)	0.067	0.3	-	1500	30

3.2. Energy analysis

Energy consumption for dry washing consist of energy used for pump to flow biodiesel inside the membrane, energy for flowing biodiesel from storage tank to feeder tank, and energy released from operator during operation [14]. Meanwhile energy consumption for water washing come from energy used for heating water by using heater, energy used for drying biodiesel using heater, energy for flowing biodiesel storage into feeder tank, and energy released from operator during operation. Table 2 shows the results of energy consumption for both biodiesel washing methods.

Table 2. Energy consumption for dry and water washing of biodiesel.

Types of washing		Energy (kJ/kg)
Dry washing		
- Pump		288
- Flow		3.28
- Operator		24.21
	Total	315.49
Water washing		
- Heater (water heating)		968
- Heater (drying biodiesel)		268
- Flow		13.09
- Operator		92.72
	Total	1361.81

Based on Table 2, the energy consumption for dry washing method can be reduced for 1046.32 kJ/kg and the energy ratio between energy for dry washing and energy for water washing was 0.23. From Table 2 , it was also exhibited that the use of dry washing methods energy released by operator was reduced from 92.72 kJ/kg to 24.21 kj/kg.

Table 3 shows biodiesel quality resulted from dry method and water washing method and such results were compared to the Biodiesel Indonesian Standard-SNI 04-7128-2006 [15] and ASTM biodiesel standard [13]. Based on the biodiesel quality testing results for both methods, the biodiesel quality parameters resulted meet the Biodiesel quality. Based on the observation, the biodiesel from dry method was not as bright than the result of biodiesel from water washing. The biodiesel's color or brightness does not indicate fuel quality, and this correlates to the color requirements of biodiesel stated by ASTM which recently passed specifications for biodiesel blends without any requirements of biodiesel color.

Table 3. Biodiesel quality resulted from dry and water washing methods.

Type of washing	Methyl ester (%)	Total glycerol (%)	Viscosity (cSt)	Acid Value (mg KOH/g oil)	Moisture content (%)	Density (kg/m^3)
Dry washing (continues)	98.65	0.24	6.00	0.41	0.04	0.86
Water washing (batch)	98.68	0.23	6.00	0.44	0.03	0.87
SNI	96.5	0.24	2.3 – 6.0	0.8 max	0.05 max	0.85 – 0.89
ASTM	-	0.24	6.0-9.0	0.8 max	0.05 max	-

4. Conclusion

The washing capacity of biodiesel washing reactor using dry method was higher than water washing method. The reactor was able to reduce the amount of washing energy of 1046.32 kJ / kg or it was 23.2 % smaller than energy for washing water. By using dry method, it was able to eliminate the use of 30 liters of water for washing of 10 kg of crude biodiesel. Another point that can be seen from the implementation of the dry washing reactor that is biological energy released from the operator was lower than those of water washing with the ratio of 2.61. This means, biodiesel washing reactor operators provide jobs 0.261 times lighter than conventional methods.

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